Italy is the Country were pasta manufacturing, along with related technical and machinery development, had and still have their top expression. From the beginning of 1900, the artificial drying process allowed pasta to be produced at industrial level and therefore to be distributed to all regions of Italy first, and then internationally (including big exportation volumes to USA). Later on, importing Countries started to produce machines to manufacture and dry their own pasta. The drying process is the final main step of industrial pasta production, and it is fundamental to greatly prolong shelf life of the product (many months to some years). With drying, the relative humidity goes from 32-35% of unleavened pasta dough to no more than 12.5% of final dry pasta. This level is sometimes even lower than the initial semolina flour humidity (e.g. 14-15%). Such deep level of dryness is not achievable with natural drying in acceptable times, therefore rooms or cabinets at controlled temperature and humidity are widely used. The exsiccation process leads to the formation of a sort of surface “crust” on pasta, but later humidity is redistributed between “heart” and surface. Since the conditions of the inlet product and the drying cabinet are very different, a thermodynamic equilibrium condition is suddenly established at the beginning of drying, then the mass transfer provides the extraction of the rest of water from the bulk of the food. A liquid diffusion mechanism in solids like dough matrixes carries water at the interface between sample and air, where evaporation occurs. Then, water diffuses as vapour through a gas medium often by a forced convection mechanism present in the drying cabinet in order to facilitate the

process. The water must be extracted so that the tension generated does not exceed the product's limit of elasticity: if this occurs, pasta will be damaged to a greater or lesser extent (cracks, splits, veining, etc.). Regarding the controlled temperatures applied for pasta exsiccation, it is possible to distinguish two different approaches:

Low temperature drying: it is a more traditional procedure, which involves prolonged exsiccation times (ca. 10-15 hours or more) at relatively low temperatures (60-70°C). For this reason, drying of high volumes of product requires big allowance of space and time, and as a result final pasta cost is quite higher. It is the drying procedure still used in many traditional and well renown Italian pasta production plants, using high range ingredients starting from semolina flour and including the kind of water used to obtain the dough.

High temperature drying: depending of course on pasta thickness, shape an initial dough humidity, pasta is dried for 2 to 10 hours at 60 to 120°C. These values are just indicative, as many different high temperature exsiccation protocols can be used by different production plants: in fact, high temperature (HT) and very high temperature (VHT) drying cycles are subgroups of this approach. An advantage of high temperature is to create pasta which has a good performance during cooking, remaining of the right consistency even if boiling is prolonged for a few extra minutes. In fact, comparing HT pasta and VHT pasta, the latter has even higher quality scores based on sensory evaluation, total organic matter dispersed in cooking media (water) after cooking, and

cooking loss of weight. These favourable effects of very high temperature drying probably depend on starch granules conformational changes (evident at X-ray diffraction), and gluten protein denaturation. Moreover, these effects are often present even if semolina flour used for the dough is not of excellent quality. Another advantage of the use of high temperatures is the achievement of an extremely safe product from the microbiological point of view. Despite all these advantages, including economical benefit thanks to much shorter drying times, high temperature drying approach can lead to some risks and damages to final products, e.g. thermo-mechanical stresses (with pasta fractures caused by different regions of pasta drying at different speeds) and non-enzymatic browning (Maillard reactions). These problems arise if parameters are not well under control, e.g. too higher temperature and/or for too long. In order to overcome these risks, controlled drying cycles are often applied, where strong exsiccation steps characterized by high temperature and low air humidity are forerun by a pre-drying step and followed by "recovery stages" at low temperature and higher air moisture content, to allow re-equilibrium deep inside the pasta. In this way, it is possible to avoid the onset of internal humidity gradient and the formation of the surface "crust", which would hinder any further exsiccation. As a result of a good drying cycle programming, overall pasta water loss is faster, and final product quality is higher. Of course, in order to realize these drying cycles, it is necessary a plant design capable of finely tuning process conditions and alternating "fast" and "soft" drying conditions. Regarding the effect of the drying step on pasta sensory characteristics, the multi-step Maillard reactions can play a role both on appearance and flavours of dry pasta: the relevance of these reactions not only depends on temperature level and length of its application, but also on raw material composition, in particular percentage of proteins and reducing sugars (both precursors of Maillard reactions products). In fact, high temperature dried pasta often has a darker/yellower aspect compared to low temperature dried one. The yellow colour could also be partly due to wheat selection in the last years, more oriented to carotenoid-rich grains. Maillard reaction entity can be monitored not only evaluating pasta colour but also, more accurately, measuring some marker substances (e.g. furosine) formation. At the end of the drying process, even if the value of moisture in the pasta is the desired one, it is necessary for it to be distributed uniformly inside the product so that all moisture gradients are zeroed (especially if the pasta was dried with WHT cycles and in a short time). The stabilization phase must keep the final moisture level in the product unchanged, even if a slight further decrease in moisture is possible. After completing stabilization, pasta can at last be cooled and reach the condition of being thermally balanced with the environment, ready for packaging. The most used pasta packaging is flow pack plastic, either for supermarket size pasta (500 g to 1 kg) or ho.re.ca sector (5 to 10 kg). Pasta shapes more prone to mechanical fractures (e.g. egg pasta) or higher

range quality pasta are often packed in paper based trays or boxes, with or without plastic sleeves or windows.

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